New Guidelines for Wind Turbine Gearboxes

Robert Errichello

GEARTECH

Disclaimer

The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.

ANSI/AGMA/AWEA 6006-A03

- Overview of gearbox issues
- Nomenclature
- Guidelines for gears
- Gear rating
- Guidelines for bearings
- Bearing rating

ANSI/AGMA/AWEA 6006-A03

- Guidelines for shafts
- Shaft rating
- Lubrication requirements
- Oil cleanliness requirements
- Oil Film Thickness
- Manufacturing requirements
- Quality assurance
- Operation & maintenance requirements

Overview of Issues

- Purchasing process
- Responsibilities of all parties
- Design requirements
- Manufacturing requirements
- Operation and maintenance requirements

Nomenclature (people)

- Purchaser
- Wind turbine manufacturer
- Gearbox manufacturer
- Bearing manufacturer
- Lubricant manufacturer
- Wind turbine operator

Nomenclature (loads)

- Rated power
- Operating torque spectrum
- Maximum operating torque
- Extreme torque
- Transient torque
- Torque-speed relation

Nomenclature (bearings)

- Basic rating life
- Advanced rating life
- Combined advanced rating life
- Dynamic equivalent load
- Miner's sum dynamic equivalent load
- Minimum required operating load

Nomenclature (bearings)

- Bearing arrangement
  - Paired
  - Combined
  - Tandem
  - Double row
- Bearing function
  - Locating
  - Non-locating
  - Cross-locating

Guidelines for Gears

- Parallel-axis, epicyclic, or hybrid
- Spur, helical, or double helical
- Carburized, hardened & ground
- Internal gears carburized or nitrided
- ANSI/AGMA 2101 grade 2 (ISO 6336-5 grade MQ)
- ISO 1328-1 grade 6

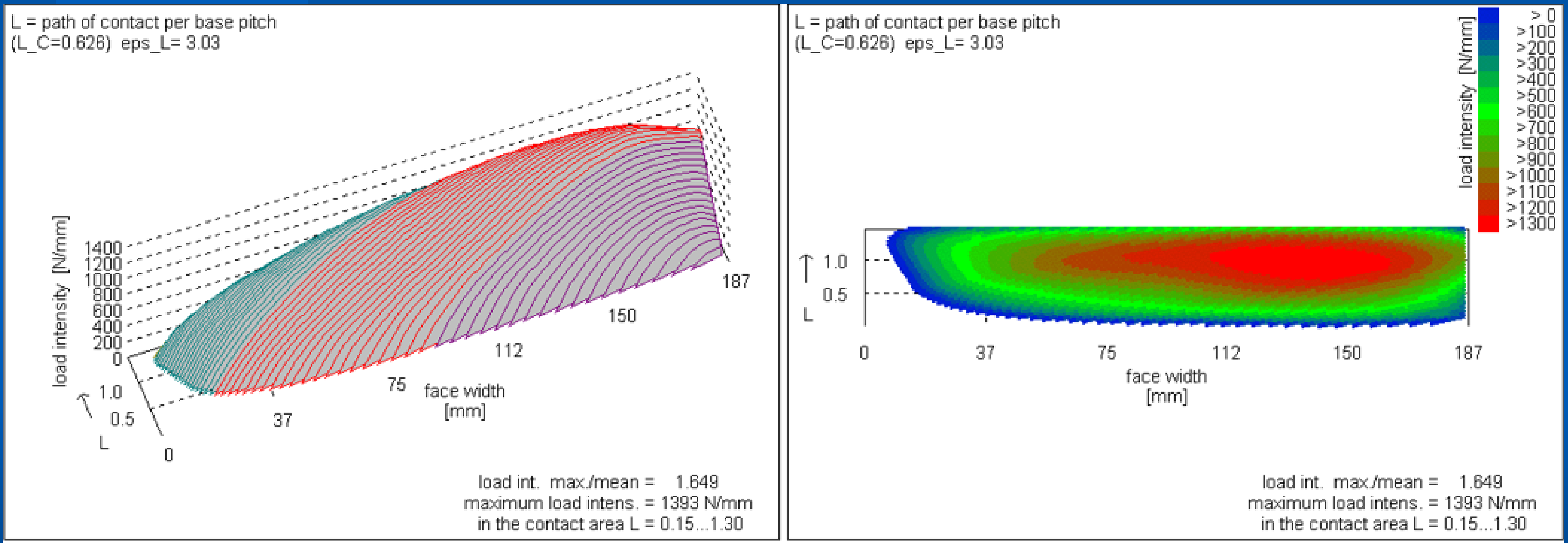
Guidelines for Gears (cont.)

- Designed per AGMA 901
- Aspect ratio < 1.25 preferred
- Profile shift to balance sliding
- Gear tooth profiles modified
- Gear tooth helix modified
- Planet rim thickness $\geq$ 3 modules

Gear Rating

- AGMA 2101 or ISO 6336?
- $K_v \geq 1.05$
- $K_{H\beta} \geq 1.15$ by advanced analysis
  - Stiffness
  - Clearance
  - Manufacturing deviations
- $K_{H\beta}$ validated by prototype test

Advanced Analysis for $K_{H\beta}$

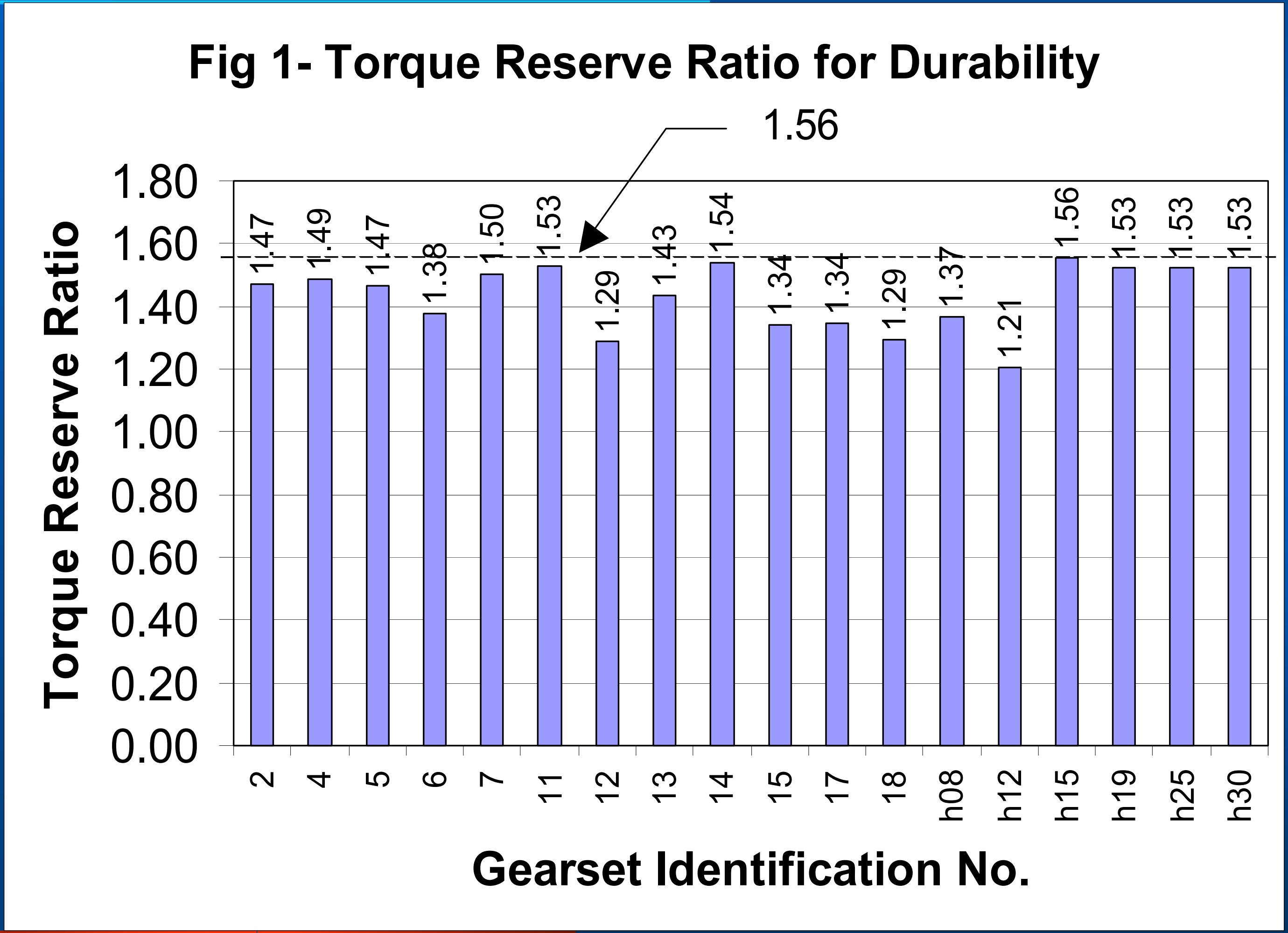


RMS lead deviation (+), right power split

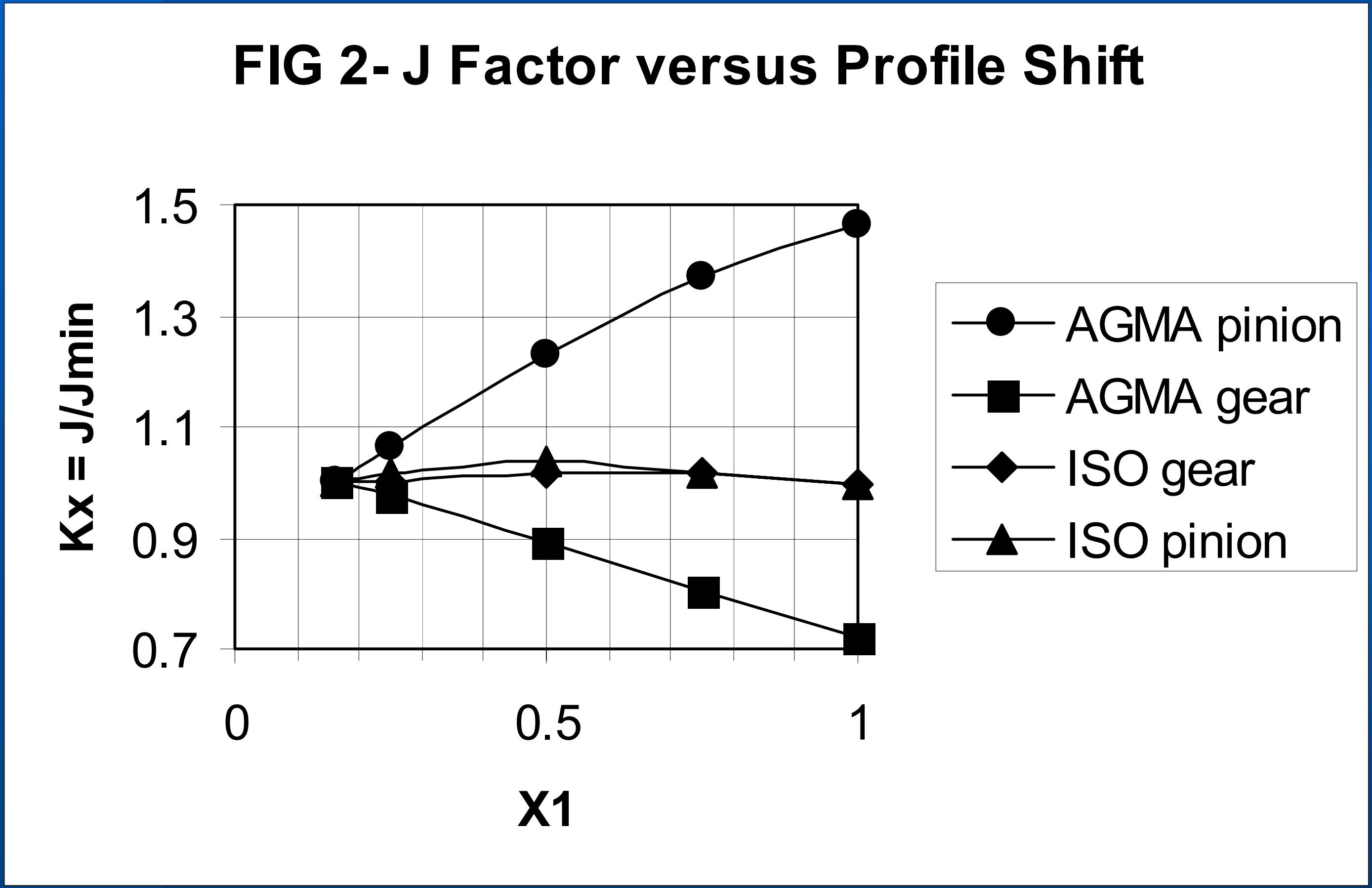
AGMA 2101 vs. ISO 6336 Study

- Example gearsets from real wind turbines were rated w/ both methods
- GEARTECH analyzed 18 gearsets [1,2,3]
- Subcommittee analyzed 6 gearsets

GEARTECH Study (results[3])



GEARTECH Study (results[2])



GEARTECH Conclusions[1,2,3]

- AGMA 2101 & ISO 6336 Ratings are different
- Sensitivity to geometry is different
- Safety factors must be different
- There is no constant factor for converting ratings

Rules: AGMA 2101 Gear Rating

- Miner's Rule required
- Reliability = 99%
- Lower life curves
- $S_H = S_F = 1.0$
- Calculated lives $\geq$ design life
- Scuffing risk $<$ 5% per AGMA 925

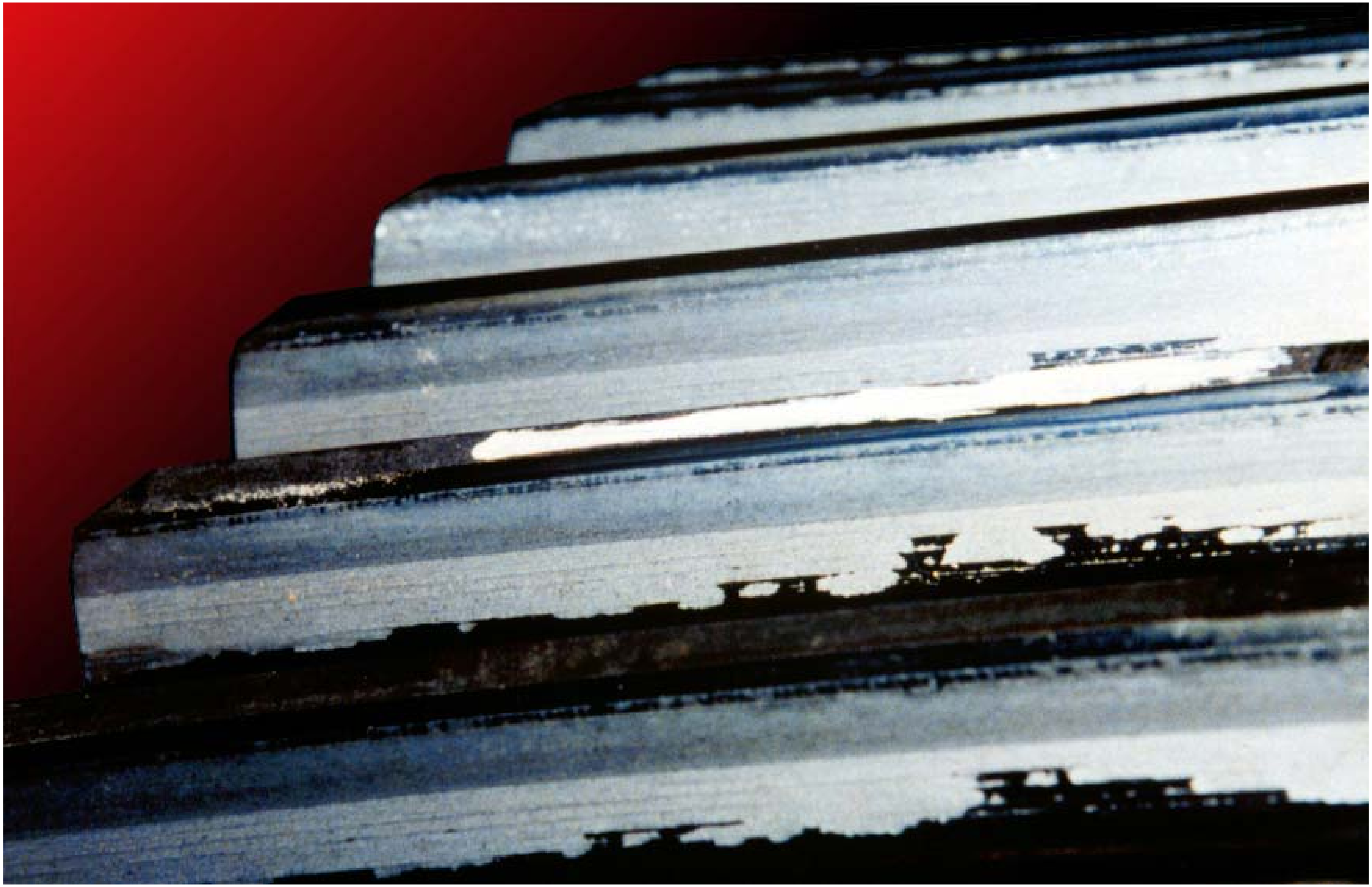
Rules: ISO 6336 Gear Rating

- Miner's Rule required
- Reliability = 99%
- Lower life curves
- Required lives $\geq$ design life
- Calculated $S_H \geq 1.25$, $S_F \geq 1.56$
- Scuffing risk $<$ 5% per AGMA 925

Micropitting Guidelines[5,6]

- FVA 54 load stage $\geq$10
- Ra $\leq$ 0.5 μm preferred
- Superfinishing may be required
- Shot peened flanks not allowed
- Run-in requirements negotiated
- Prototype tests negotiated
- Start-up requirements negotiated

Hertzian Fatigue/Micropitting



Micropitted gear teeth appear dull, etched, or stained with patches of gray. It attacks high points on gear tooth surfaces such as crests of undulations, peaks of cutter scallops, and ridges of grinding lay.

Guidelines for Bearings

- Selection matrix for each shaft
  - ● – Suitable
  - ◐ – Suitable with restrictions
  - ○ – Not experienced
  - ⊖ – Not suitable
- Shaft and housing fits tight
- Steel or brass cages preferred
- Clearance controlled
- Risk of assembly damage controlled

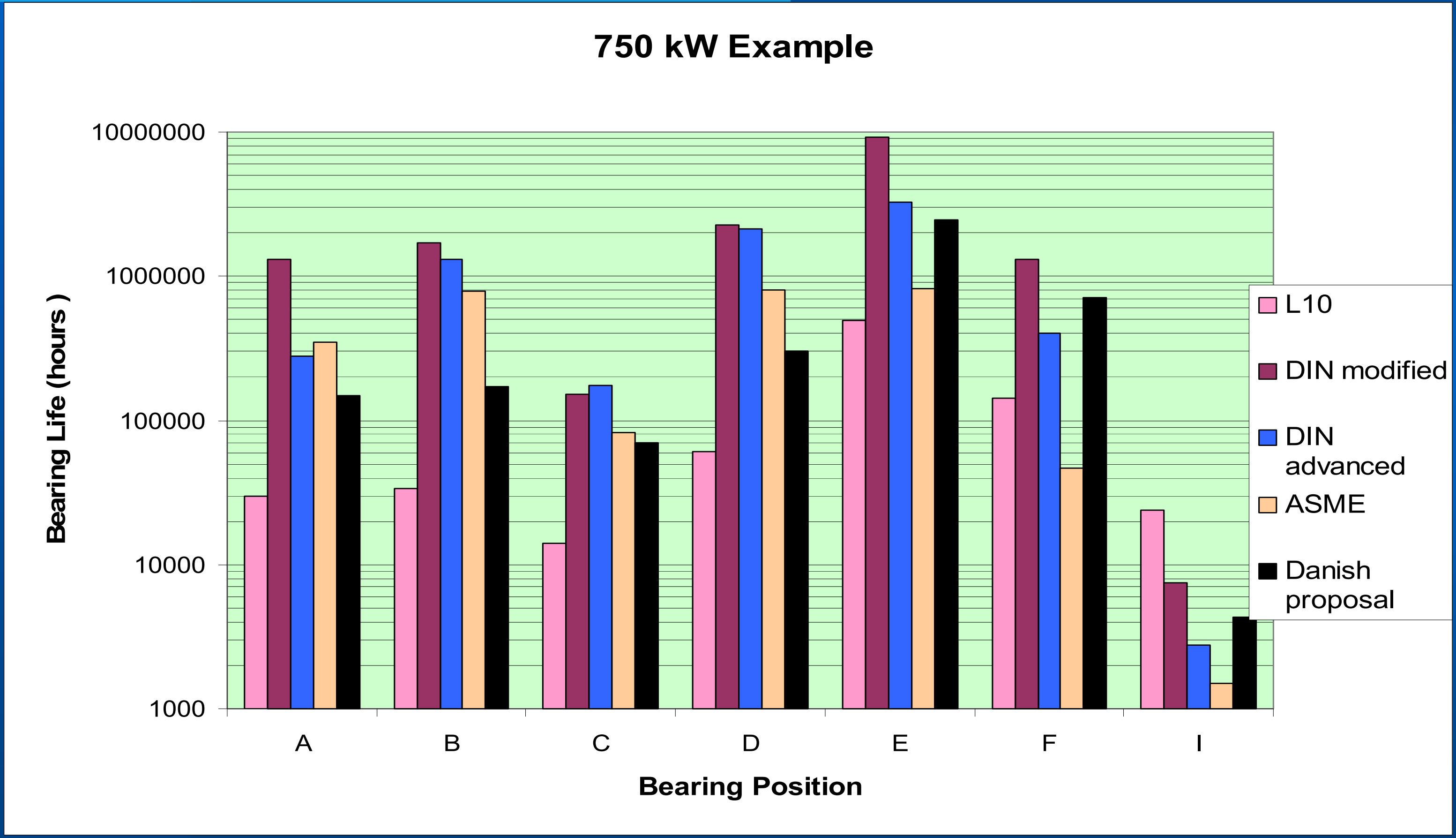
Bearing Rating Methods

- Static safety factor $\geq$ 3 at max load, $\geq$ 2 at extreme load
- Life rated per DIN ISO 281 Bbl. 4
- Advanced methods may be used
- Compare life to basic equation
- Compare contact stress
- Resolve differences

Bearing Rating Study

Power (kW)	Gearbox type and vintage
225	Helical typical of 1980's
600	Hybrid typical of early 1990's
750	Late 1990's widespread brg failures
1500	Late 1990's some brg failures
2000	Late 1990's some brg failures

Bearing Rating Study Results



Bearing Study Conclusions

- Different methods give different lives
- Advanced methods vary w/ mfgr.
- Basic rating life should be guideline
- DIN ISO 281 Bbl. 4 should be used
- Differences between DIN ISO 281 and advanced methods must be resolved
- Stress method used as sanity check

Basic Rating Life

$$L_{h10} = \frac{10^6}{60 * n}\left(\frac{C}{P}\right)^p$$

Guidelines (basic rating life)

Bearing shaft	Required life L_{h10} (hours)
HS	30,000
HS/INT	40,000
LS/INT	80,000
Planet	100,000
LS	100,000

Bearing Rating (DIN ISO 281)

- Operating temperature defined
- Operating clearance defined
- Oil cleanliness defined
- Advanced methods may be used
- Differences between DIN ISO 281 and advanced methods must be resolved

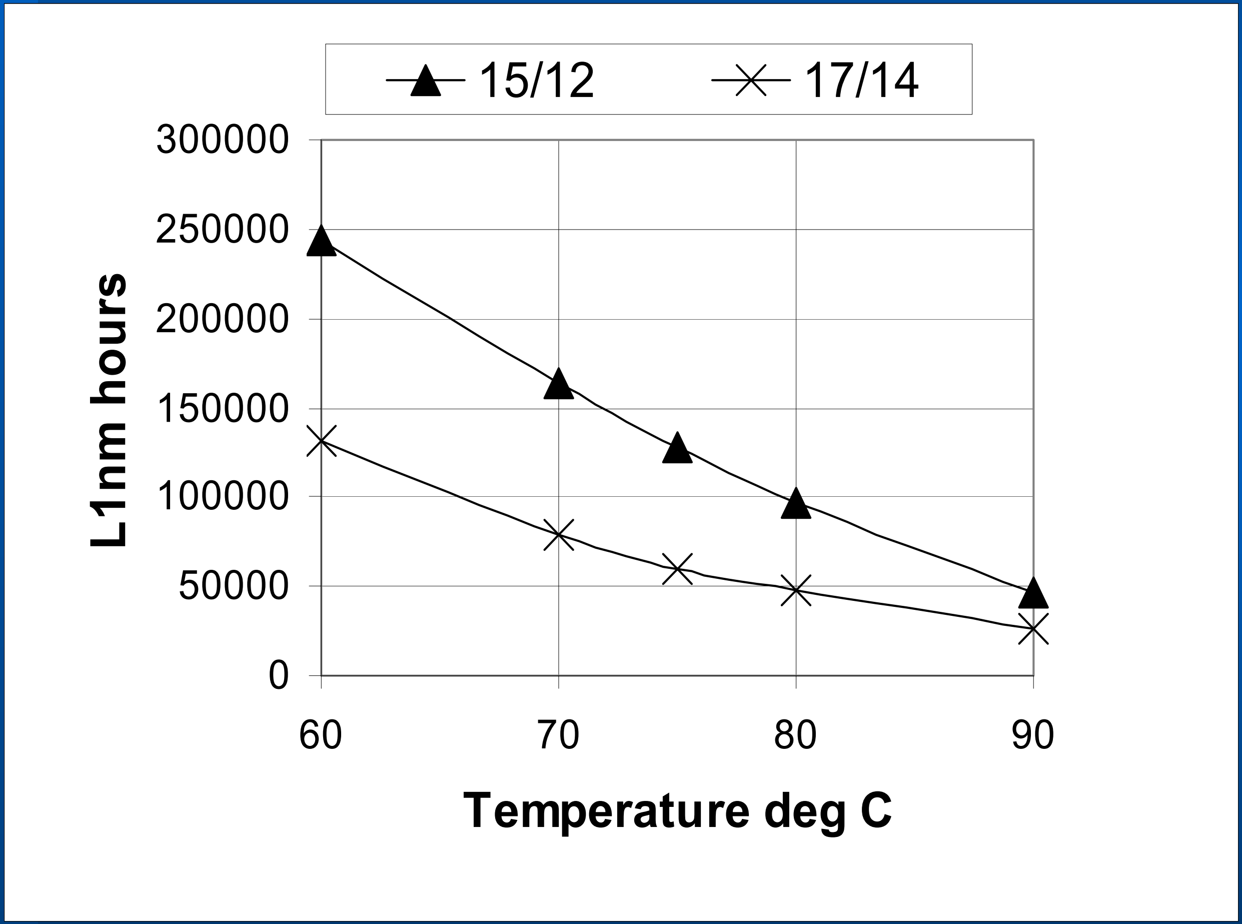
DIN ISO 281 Rating

$$L_{1nm} = a_1 * a_{DIN} * L_{h10}$$

$$a_1 = 0.21$$

$$a_{DIN} = f\left[e_c, \frac{C_u}{P}, \kappa \right]$$

Brg Life vs. Cleanliness & Temp



Bearing Rating (contact stress)

$$p_{\max} = K_{lc} * K_m * p_{line}$$

$$K_{lc} = \text{curvature factor}$$

$$K_m = \text{alignment factor}$$

$$p_{line} = 270 * \sqrt{\frac{1}{2} * \left(\frac{Q}{L_{we}}\right) * \Sigma\rho_{line}}$$

Guidelines (contact stress)

Bearing shaft	Max contact stress p_{max} (MPa)
HS	1300
HS/INT	1650
LS/INT	1650
Planet	1450
LS	N/A

Guidelines for Shafts

- Adequate strength and fracture toughness
- Stress risers minimized
- Interference fit must transmit max reversing torque
- Splines designed to prevent fretting corrosion (preferably nitrided)

Shaft Rating

- AGMA 6001 or DIN 743?
- Reliability = 99%
- Calculated life ≥ design life

Lubrication Requirements

- Lubricant type and viscosity
- Application method
- Minimum oil quantity
- Temperature control
- Oil cleanliness
- Filtration (inline and offline)
- Monitoring

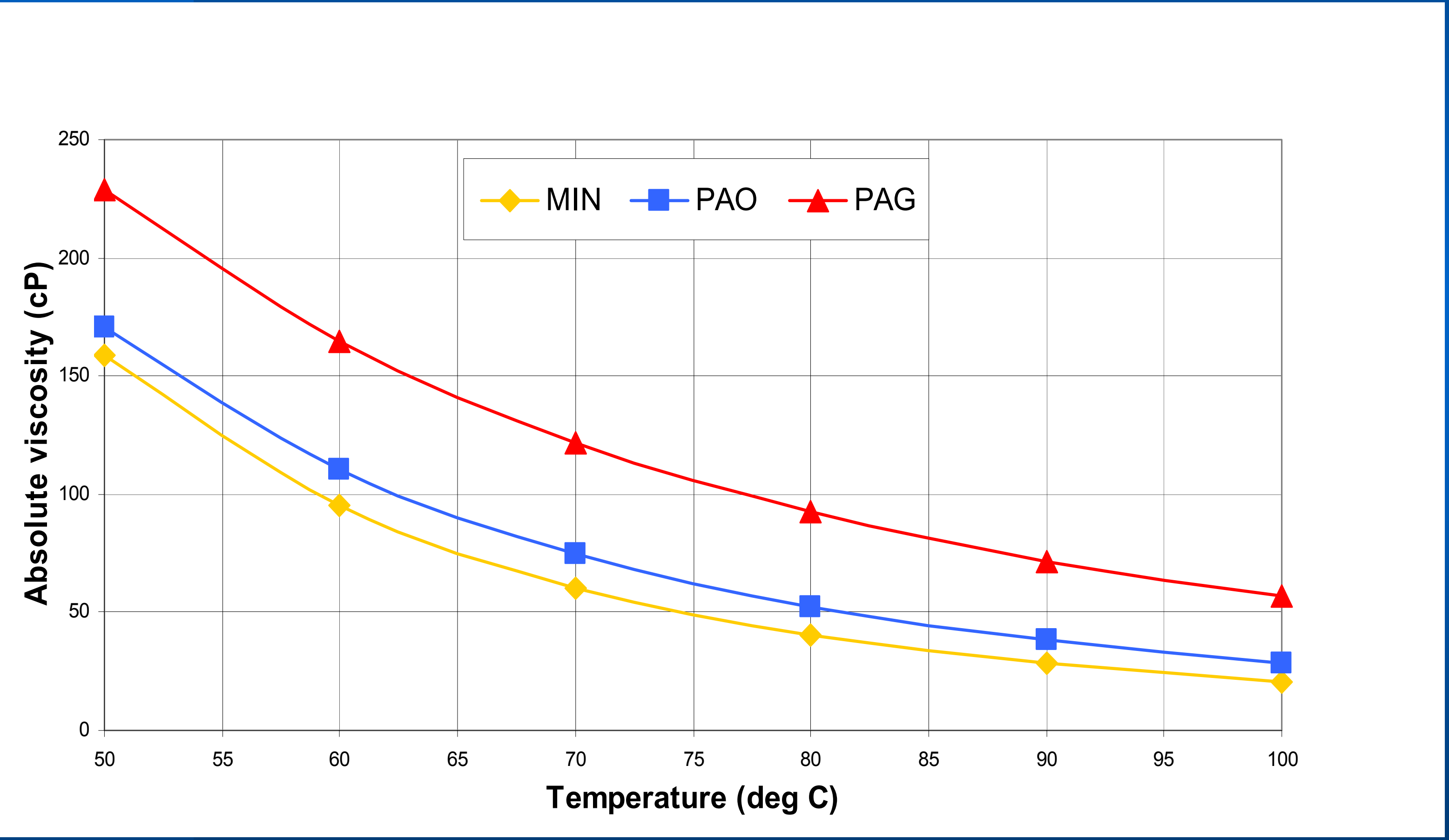
Oil Cleanliness Requirements[5]

Source of oil sample	Required Cleanliness per ISO 4406:1999
Oil added to gearbox	-/14/11
Gearbox after factory test	-/15/12
Gearbox after 24-72 hr service	-/15/12
Gearbox in service	-/16/13

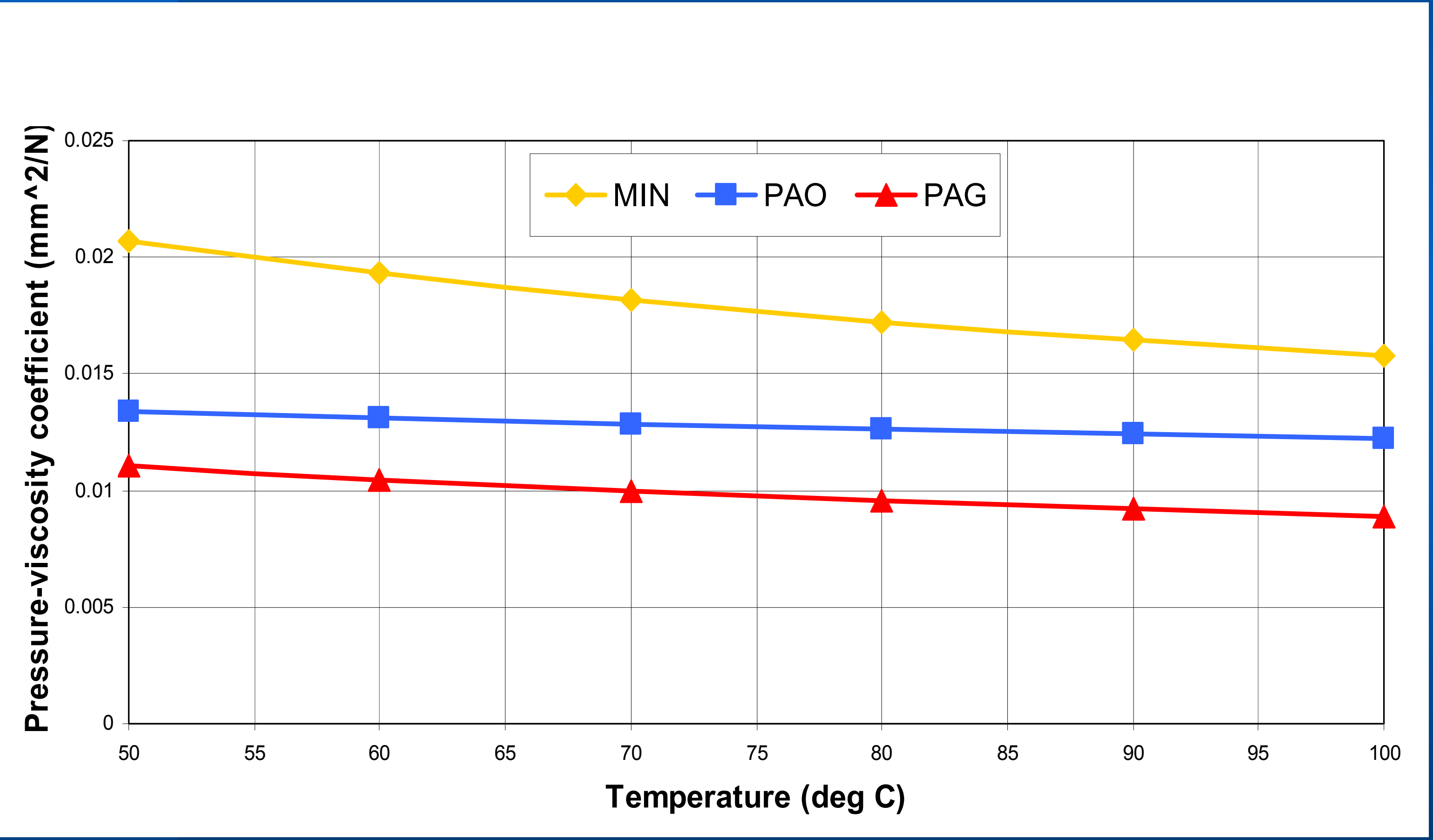
Film Thickness Depends on α, η_0

$$H_c \propto \alpha^{0.56} * \eta_0^{0.69}$$

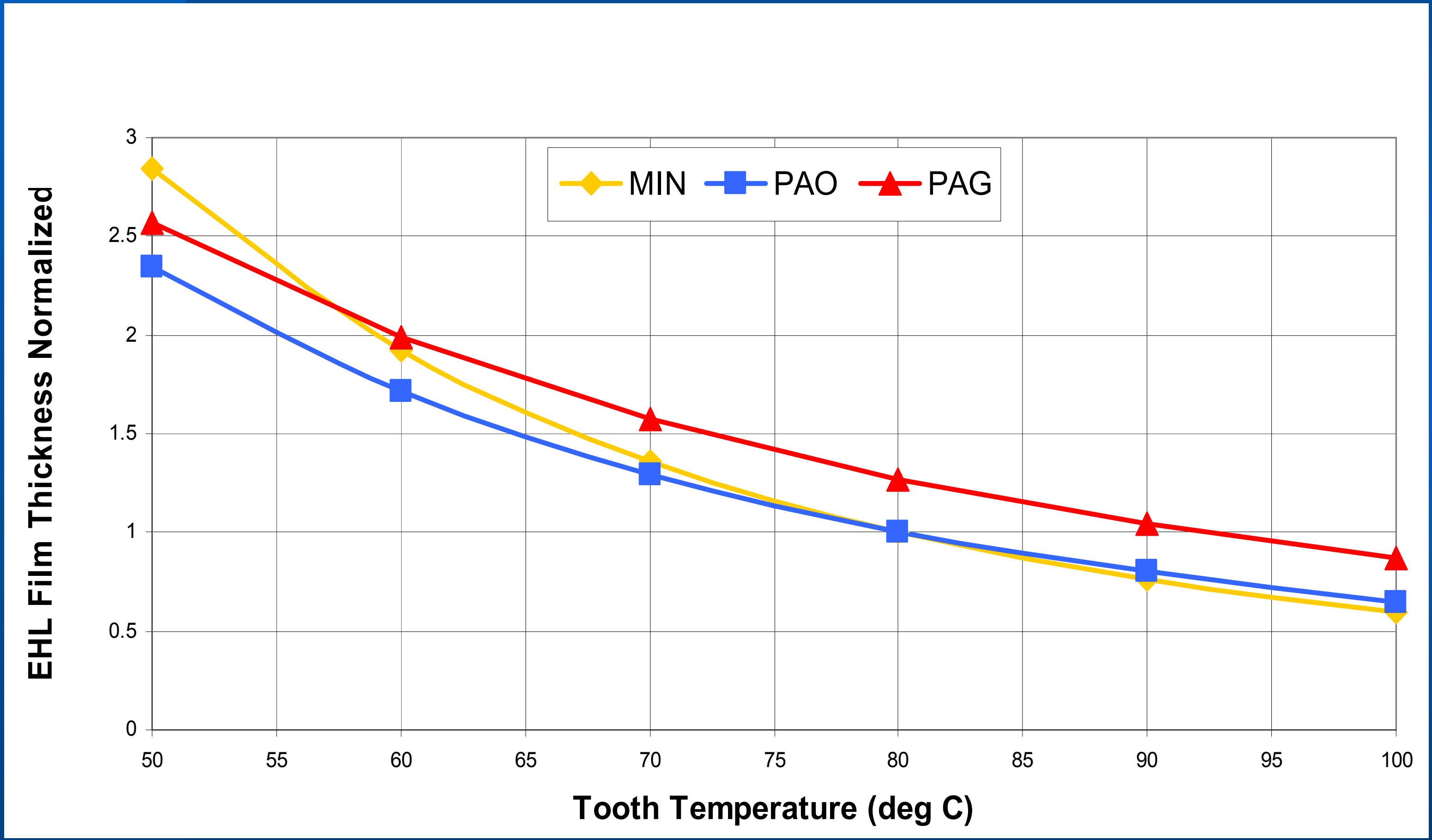
Viscosity v. Temperature[4]



P-V Coeff. α v. Temperature[4]



EHL Film Thickness v. Temp.[4]



Manufacturing Requirements

- Gear metallurgical quality
- Gear geometric accuracy
- Tooth microgeometry
- Method of manufacture
- Grinding notches not allowed
- Tooth surface roughness
- Surface temper inspection

Quality Assurance (Annex C)

- Explains procurement process
- Procurement specification
- QA plan
- Manufacturing schedule
- Design audit
- Mfg audits- QA plan, mfg, tests
- Resolving mfg deviations

Operation & Maint. (Annex D, F)

- Startup and run-in
- Filtration systems
- Coolers and heaters
- Condition monitoring
- Lubricant sampling
- Lubricant testing

Summary of Guidelines

- Purchasing process
- Responsibilities of all parties
- Design requirements
- Manufacturing requirements
- Operation & maintenance requirements

AGMA 2101 vs. ISO 6336 Refs

1. GEARTECH Report No. 1974, "Comparison of ISO 6336 and AGMA 2001 Load Capacity Ratings for Wind Turbine Gears."
2. GEARTECH Report No. 1992, "Sensitivity Study for Profile Shift, Helix Angle, and Normal Pressure Angle."
3. GEARTECH Report No. 2025, "Torque Reserve Ratio."

Lubrication References

4. GEARTECH Report No. 2038, "Comparison of EHL Film Thickness vs. Temperature Characteristics of Mineral, PAO, and PAG Lubricants."
5. "Oil Cleanliness in Wind Turbine Gearboxes," Machinery Lubrication, July/Aug 2002, pp. 34-40.

Lubrication References (cont.)

6. "Selecting and Applying Lubricants to Avoid Micropitting of Gear Teeth," Machinery Lubrication, Nov/Dec 2002, pp. 1-9.
7. "Another Perspective: False Brinelling and Fretting Corrosion," Tribology & Lubrication Technology, April 2004, pp. 34-36.

Thanks for your attention!